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ON SEISMIC MOTION AND SOME RELATIONS OF EARTHQUAKES TO OTHER PHENOMENA.[1]

By F. OMORI.

Earthquake.—An earthquake consists, as the name signifies, in the trembling of the ground, and may be defined as vibrations or wave-movements propagated through rocks and soil, the motion diminishing with the increase of the distance from the source of disturbance. The magnitude or energy of an earthquake, taken as a whole, may be represented by the area within which the motion is felt; while the intensity of motion at a given place, which depends on the size of the earthquake, decreases in an inverse proportion to the distance. Thus, according to the depth of the earthquake center, there may be large disturbances in which the motion at the surface is not extremely violent, as well as small ones, in which the motion is quite severe.

Disturbance of Waters.—When the earthquake motion of inland origin is large and violent, the waters of ponds, rivers, or lakes are more or less disturbed. So, similarly, a great submarine earthquake is often followed by tidal waves; the time interval between the occurrence of the earthquake shock and the arrival of the sea-waves depending on the depth of the water and the distance of the origin from the shore. The tidal waves following the great Japan earthquake of December 23, 1854, which wrecked the Russian frigate "Diana," then at anchor in the harbor of Shimoda, crossed the Pacific, and were recorded by the tide-gauges at San Francisco and other places on this coast of America.

[1] Read June 26, 1906, before an adjourned meeting of the Society. Abstracted by A. O. LEUSCHNER.

Tidal waves, which are not to be noticed on the high sea, are developed most markedly on indenting bays with shallow waters. Many of the great earthquakes originating off the Pacific coast of Alaska and Central and South America have been accompanied by large tidal waves. But fortunately this phenomenon, which sometimes causes more damage than the earthquake disturbance itself, has so far not been very active along the coast of the United States. The great earthquake of April 18th last produced distinct but very small disturbances of the bay waters, which were clearly recorded by the tide-gauge at the Presidio. An examination of the marigrams at several stations on the Pacific Coast of Japan and different places in India has shown that different parts of seacoast have their proper period or periods of waves,—that is to say, each particular portion of seacoast is virtually a fluid pendulum whose boundaries are determined by the form of the bottom and the contour of the shore-line. Accordingly, the wave period or periods at a given coast place remain constant in all the tidal waves, irrespective of the origin or cause, a destructive tidal wave consisting simply in the amplification of the wave motion *existing more or less at all times,* in consequence of a strong submarine earthquake, a storm, or some other agency. A seismic tidal wave is caused by the movements communicated from the sea-bottom to the water mass, a very large wave disturbance taking place when the earthquake focus is at the sea-bottom itself or at a very small depth below it.

Dependence of Earthquake Motion on Nature of Ground.—As an earthquake consists in the vibration of the ground, and the range of motion, or amplitude, of an earth particle is greater in a soft than in a hard medium, it is evident that the intensity must depend much on the nature of the ground, often differing considerably even within a limited area. The seismic damage is always very slight on hard, rocky ground, and severest on soft, incoherent soil, and especially on newly made ground. From this fact it will be seen at once that the foundation-making plays a most important part in the earthquake-proof construction of buildings and engineering structures. By making the foundation large and solid we approach the condition of a rocky ground. If the foundation be, on the other hand, small and weak, the structure resting on it

will be virtually a group of different bodies loosely bound together, and will be thrown into large movements, causing a mutual destruction. As the length of the elastic or proper earthquake waves constituting a destructive shock must be about two to three miles, the slight curvature into which the ground surface is thrown on such occasions will not be evident to the eye. It seems, however, that in a soft, marshy soil a violent earthquake sometimes produces, as a secondary phenomenon, a sort of semi-gravity vibration of short wave-lengths, say about twenty or thirty yards. The latter motion, which will be visible to direct observation, and which may be called "visible surface motion," often throws the ground into remarkable curved forms and is very dangerous to structures. But injurious effects of this sort can be entirely avoided by making the foundation of a structure sufficiently large and solid, thereby reflecting back the disturbance consisting of short wave-length vibrations. The case is analogous to the effect of water-waves on bodies floating on the surface. Thus a small fragment of wood or straw behaves as if it were a particle of the water and moves together with the small ripples; but a large vessel at anchor in a harbor will not be affected by the waves on account of its mass and size.

It may be noted that high ground is, except sand-dunes, generally hard, and therefore good as the site for buildings. But a steep slope or the vicinity of a cliff must be avoided, as the earthquake motion is in such places considerably augmented, owing to the absence of support on the side.

Tremors and Pulsatory Oscillations.—We are accustomed to regard the Earth as solid and firm. But it is a great mistake to suppose that the ground is at rest when we do not *feel* an earthquake. As the Earth's crust is an elastic body, we must assume, in a general way, that it is always making some movements. And so it does in reality, there being besides the tilting or inclination of the ground-level three principal sorts of vibratory movements, as follows: (1) Tremors of artificial origin; (2) Small, slow motions, called pulsatory oscillations; (3) Earthquakes.

Among the insensible tremors of an artificial origin I may mention those due to the working of dynamos, steam-engines, steam-hammers, etc. The motion produced by such causes is extremely small, and is generally, except in the immediate

vicinity, insensible. It is transmitted, however, sometimes to a distance of half a mile or more, and sets different objects in unstable conditions, so to speak, spontaneously in motion. Thus windows and doors are caused to rattle, bottles on tables to shake, suspended articles to swing, etc., becoming a source of mystery to people in the neighborhood and even giving rise to rumors of ghosts.

Causes of Earthquakes.—The ultimate causes of great earthquakes are probably to be traced to the cooling and contraction of the Earth, and in some degree to the change of distribution of the matter constituting the land and ocean-bottom. The more immediate cause of such earthquakes is, however, frequently due to the activity of mountain-making forces which produce folding or fracturing along extended zones; and any sudden disturbance in the Earth's crust, such as the splitting asunder, fracturing, or falling down of subterranean rock masses, may become the source of earthquake motion. Different external agencies which act on the Earth, and many of which are periodic, may be regarded as secondary causes of earthquake. Thus it will be seen that seismic phenomena, which are themselves periodic in nature, must have certain time and space relations.

After-Shocks.—Numerous small shocks invariably follow a great earthquake. When the latter is violent and destructive the number of these after-shocks may amount to hundreds, or even thousands, and continue for several months or several years. The occurrence of after-shocks is quite natural and necessary for the settling down into stable condition of the disturbed tract at or near the origin of the initial earthquake. Now, the mean time variation of after-shocks follows a very simple law, and analytically may be represented by means of a rectangular hyperbola. In the case of the great Japanese earthquakes of 1891, I calculated an empirical formula from the number of after-shocks observed during the first five days after the initial disturbance, and was enabled thereby to predict the general course of subsequent phenomena, such as the number of years during which these shocks should continue to happen, the total number of after-shocks from beginning to end, or the number of after-shocks during a certain year. Similar calculations have been made, with equally satisfactory results, for the after-shocks of other recent

Japanese earthquakes. Examples like these show that earthquake phenomena, though apparently mysterious, are not always so very complicated and arbitrary. In the case of the California earthquake of April 18th last, the after-shocks seem to be comparatively very few for some reason or other. These minor shakings, which will continue to happen at intervals for a few years to come, are of course harmless in nature.

Time relations of earthquakes may be distinguished as periodic and semi-periodic. Among the latter class may be included destructive earthquakes which tend to occur in groups,—that is to say, to happen in different regions of a given earthquake zone in the course of a few years. Then there follows a period of rest, after which the seismic activity again commences.

The most well-marked among the periodic seismic variations are those relating to the position of the Sun and the Moon. Thus there are annual variations in the number of earthquakes,—namely, earthquakes occur more frequently in certain months of the year than at others. So again there are more earthquakes during certain hours of the day than during others. The direct principal cause for these variations is, however, not the attraction of the Sun, but the changes in the pressure of the atmosphere. This is in reality the connection between the weather and earthquakes, although the so-called "earthquake weather," or a warm or moist day, is by no means a sure precursor of tremblings of the ground. On the contrary, the high barometric pressure corresponding to fair weather seems to bring more earthquakes when the latter are not of a submarine origin. Again, the study of after-shocks has shown clearly the existence of other periods whose lengths are respectively twelve, eight, six, and four hours, and also those whose periods are four or five days, eight or nine days, twelve days, etc.

With respect to the lunar influence, there are certain relative positions of the Earth and the Moon at which more earthquakes take place than at other positions. This effect is again not due to the direct attraction of the Moon, but to the variation of the weight of water in the tidal movements. The annual, diurnal, lunar, and some other relations of earthquakes must be treated separately for each given district so as to bring out the local peculiarity.

The attraction of the planets on the Earth will have no appreciable effect on earthquake phenomena.

Latitude Variation.—Apart from the earthquake movements, pulsatory oscillations, and slight changes in the ground-level, the axis of rotation of the Earth is continuously shifting its position through a very small angle, giving rise to the variation of latitude. Professor MILNE and the late Dr. GANCAIN were the first to examine the relations between this phenomenon and great earthuakes, the conclusion reached being that a greater number of the latter occurred in those years in which the variation of latitude was greatest. From an examination of the mean monthly values of the latitude of Tokyo, I have found that all the destructive earthquakes of recent years in Japan occurred exactly or very nearly when the latitude was at a maximum or minimum.

Magnetic Disturbances.—As the magnetic property of rocks and metals varies with the strains to which they are subjected, a great earthquake, which means the removal of an enormous stress in the Earth's crust, may be supposed to be preceded or accompanied by some disturbances in the terrestrial magnetism, at least when the depth of the seismic origin is small. The relation in question has not yet been satisfactorily investigated, but in some cases the terrestrial magnetism which had been quiet for a long time became markedly disturbed a few days before a large earthquake. In this connection, it is interesting to note that the great eruption in Martinique was accompanied by a well-defined magnetic disturbance.

Geographical Distribution of Earthquakes.—In the first place, a country or district which has many volcanoes is one where the Earth's crust is weak, and consequently is often disturbed by underground convulsions or earthquakes. It does not follow, however, that earthquakes are most frequent around a volcano. On the contrary, the immediate vicinity of a great active volcano is sometimes free from very violent seismic disturbances. Broadly speaking, strong or extensive earthquakes most frequently happen along the region adjacent to the steep sides of a great mountain range or of a series of islands. The variation of gravity in an earthquake country may also have something to do with earthquake geography, and there are cases in which destructive shocks have occurred in the district of a minimum gravity force.

Future studies in various phenomena connected with the movements of the Earth's crust may perhaps tend to advance our knowledge respecting the problem of the prediction of great earthquakes which are often preceded by what may be called "fore-shocks." In the mean time and always it will be necessary to build houses and other structures strong enough to resist earthquake shocks.

San Francisco, June 26, 1906.

THE LATITUDE OF UKIAH BEFORE AND AFTER APRIL 18, 1906.

By Sidney D. Townley.

After investigation had shown that the earthquake of April 18th was caused by horizontal shearing along a geological fault running in nearly a straight line from the vicinity of San Juan, in San Benito County, to near Point Arena, in Mendocino County, and that relative displacements along the line of fault had been found, amounting, in one instance at least, to as much as twenty feet, the question naturally arose, Have the latitudes and longitudes of places near the fault-line been disturbed in a measurable degree?

The International Latitude Observatory at Ukiah, where continuous observations for the variation of latitude are made by the writer for the International Geodetic Association and under the superintendence of the United States Coast and Geodetic Survey, is situated about twenty-six miles to the east-northeast of the point where the fault-line enters the Pacific Ocean near Point Arena. That a displacement of a measurable amount could have taken place at that distance from the fault-line seemed highly improbable, but an approximate reduction of all the observations for latitude made on April 16th, 17th, 18th, and 19th showed an apparent displacement of three feet to the south. On account of the small number of observations involved and the approximate nature of the reductions, this apparent shift could not be looked upon as certainly real.

As these computations did not settle the matter one way